



US LHC Accelerator Research Program

bnl - fnal - ibnl - slac

Materials Support

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LARP Collaboration Workshop
April 6-8, 2005



Materials WBS 2.4.1

- *WBS 2.4.1.1 Strand R&D* E. Barzi
- *WBS 2.4.1.2 Cable R&D* D. Dietderich



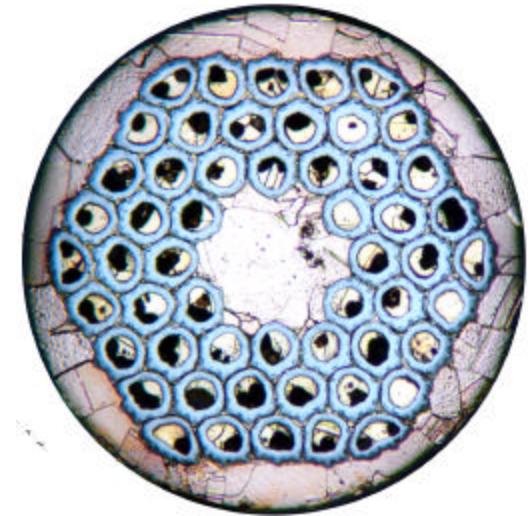
Outline of presentation

- Strand Procurement
- Strand R&D
 - J_c , RRR, Magnetization $\rightarrow D_{\text{eff}}$, Stability $\rightarrow J_s$
- Cable R&D
 - TQ prototype cable



Strand Procurement

- Long-lead item ~ 6-9 months
- Need to place orders in FY05
 - Replace conductor borrowed from HEP Conductor Development Program, and from FNAL base program (used for TQ1a & TQ2a)
 - Conductor for coil fabrication in 2006.
- Present source
 - OST
 - RRP 54/61 design



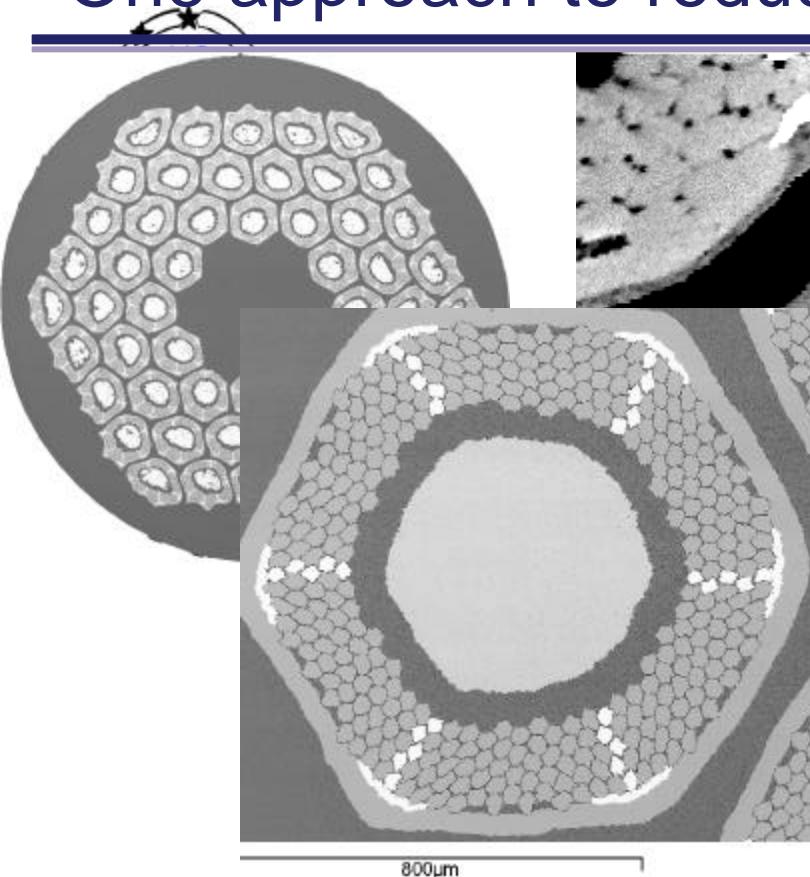


Strand Requirements

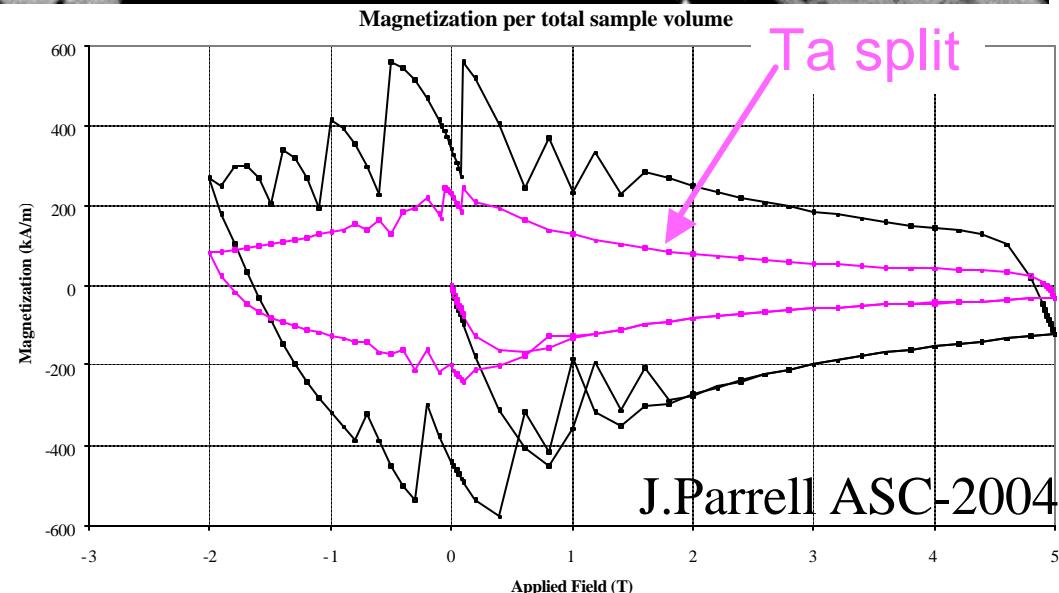
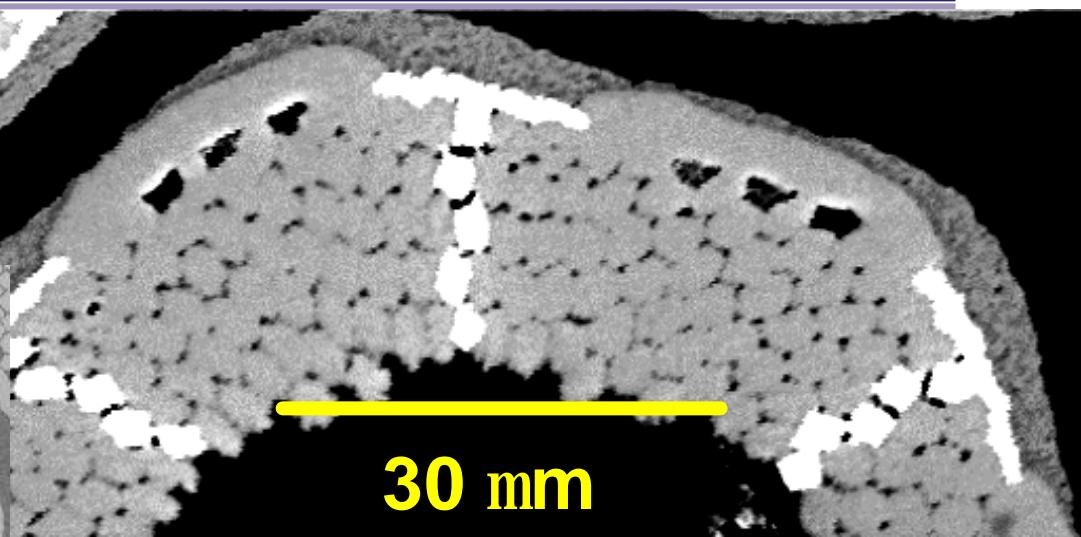
- Conductor Development Program
 - 3000A/mm^2
 - 40 micron sub-elements
 - 10,000m piece lengths

Parameter	Near Term (1-2 yrs)	Long Term (>2yrs)
Diameter (mm)	0.7-0.8	0.6-1.0
Cu fraction	~0.5	0.4-0.5
Deff (microns)	70-80	40-55
Jc (A/mm ²)	2500-3000	~3,000
RRR	20-100	20-100

One approach to reduce D_{eff} : split the subelement

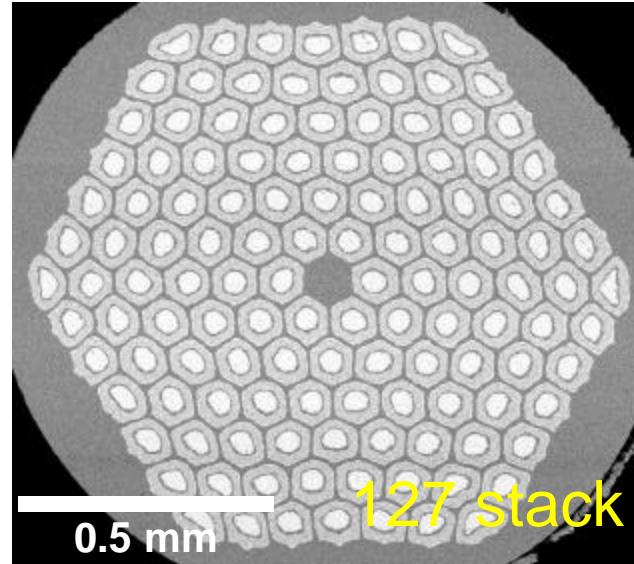
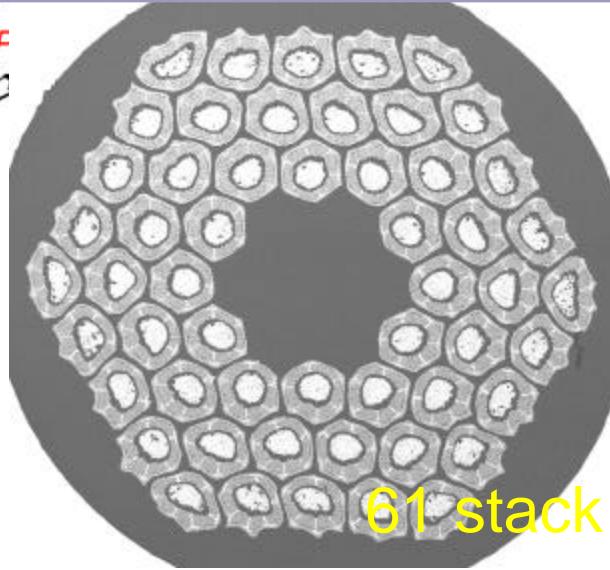


- Ta rods divide the Nb_3Sn
- Effectively reduces D_{eff}



- Excessive Ta work hardening causes wire breaks in full-size billets

Another way to reduce D_{eff} : restack more bundles



- Direct way to reduce D_{eff}
- Challenge to achieve good bonding during cold drawing due to increased Cu/Cu surface area
- Experimenting with modified subelement designs to counteract finer structure
- Not yet sure of impact on RRR

Wire diameter	Subelement size	
	61 stack	127 stack
1.0 mm	100 μm	68 μm
0.8 mm	80 μm	55 μm
0.6 mm	60 μm	41 μm
0.4 mm	40 μm	27 μm

P.Parrell ASC-2004



Strand R&D

Main Objectives and Features

- In the near term:
 - Predict the performance of TQ1 and TQ2 by measuring and understanding the material behavior from round strand through all cable and magnet fabrication processes.
 - Evaluate the effect of keystone angle for cables of given width compression by measuring the performance of strands extracted from the cables
 - Perform heat treatment studies on both round and extracted strands, to optimize I_c and RRR for the final cable.
 - Define strand specs and procure strand for FY06.

Long-term :

- Activities closely tied to strand development and cabling R&D
 - Strand stability
 - Effect of cabling on I_c degradation
 - Transverse stress effects in strands and cables



Strand Testing Setups

MAX FIELD/POWER SUPPLY MAX CURRENT:

FNAL: 15/17 T, 1800 A; 14/16 T, 1000 A (by end of Apr'05).larger bore

LBNL: 15 T, 2000 A

BNL: 11.5 T, 1200 for VH, 1500 A for VI

FOR STRAND TESTS:

FNAL: Low resistivity probe (< 40 nOhm) for I_c

Balanced coil magnetometer for magnetization (15 T max)

Probe for I_c tests under transverse pressure, 15 tons max

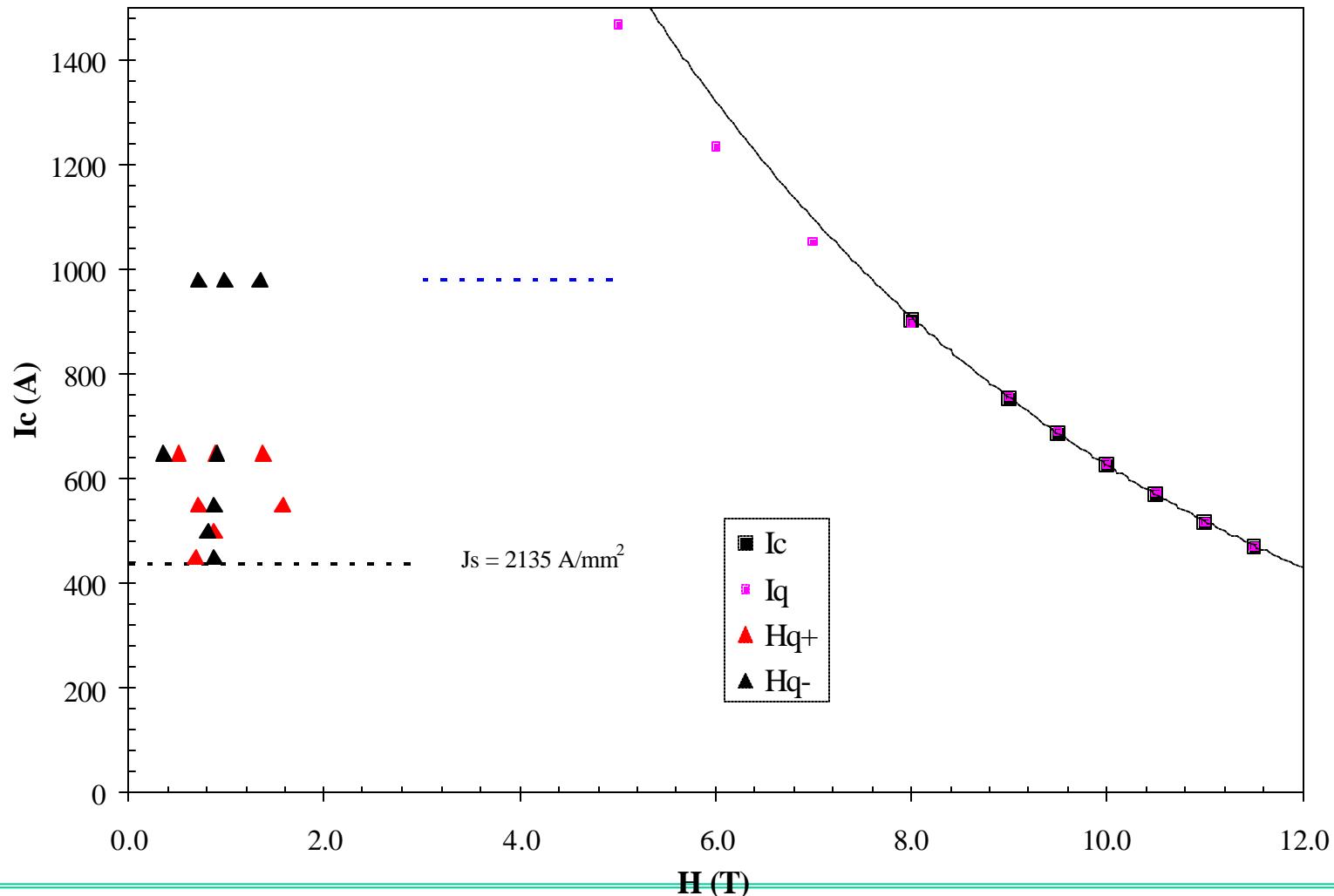
LBNL: Low resistivity probe (< 30 nOhm) for I_c

BNL: Low resistivity probe (~ 25 nOhm) for I_c

Squid magnetometer for magnetization (5 T max)

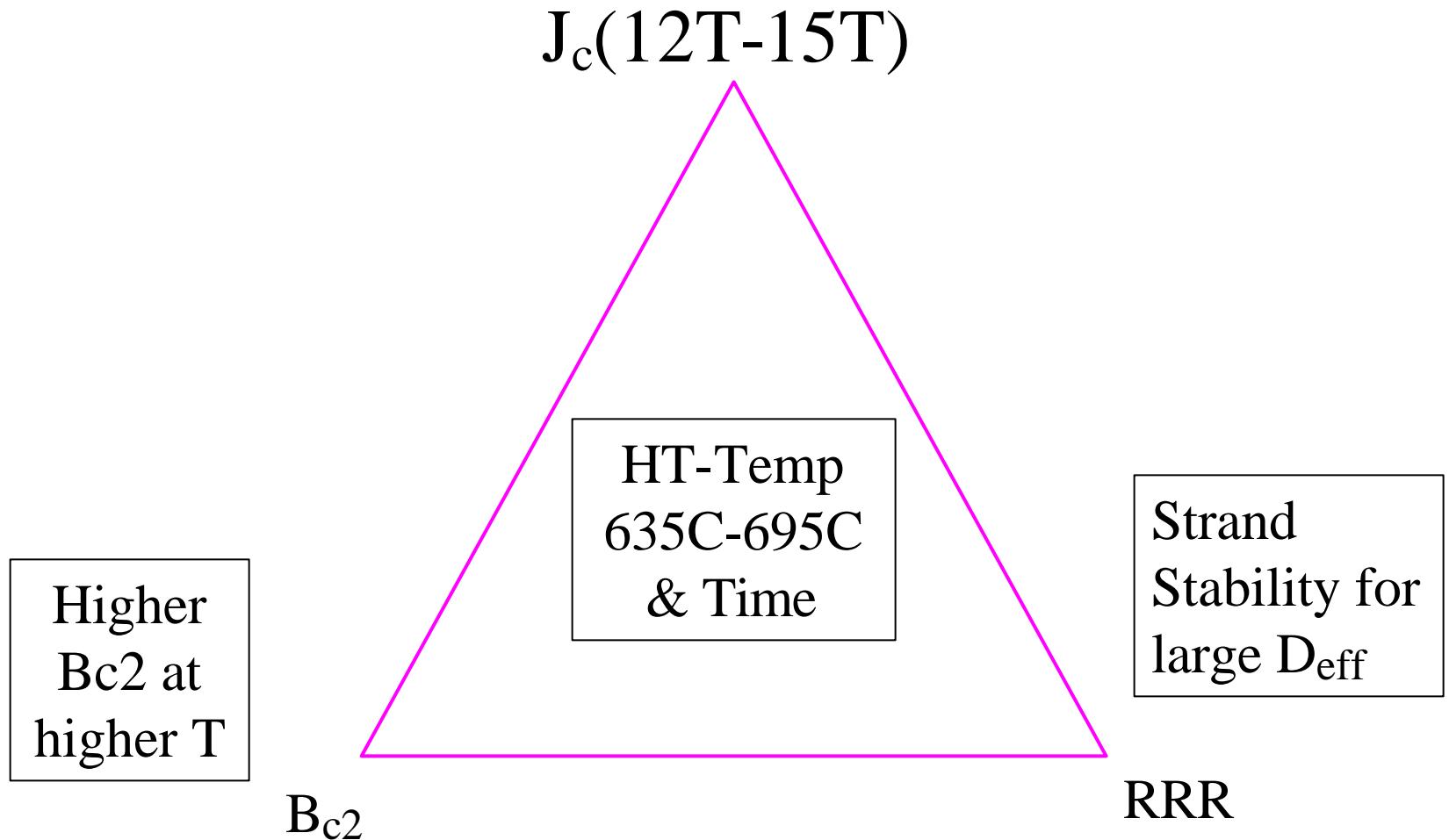


Example of Test





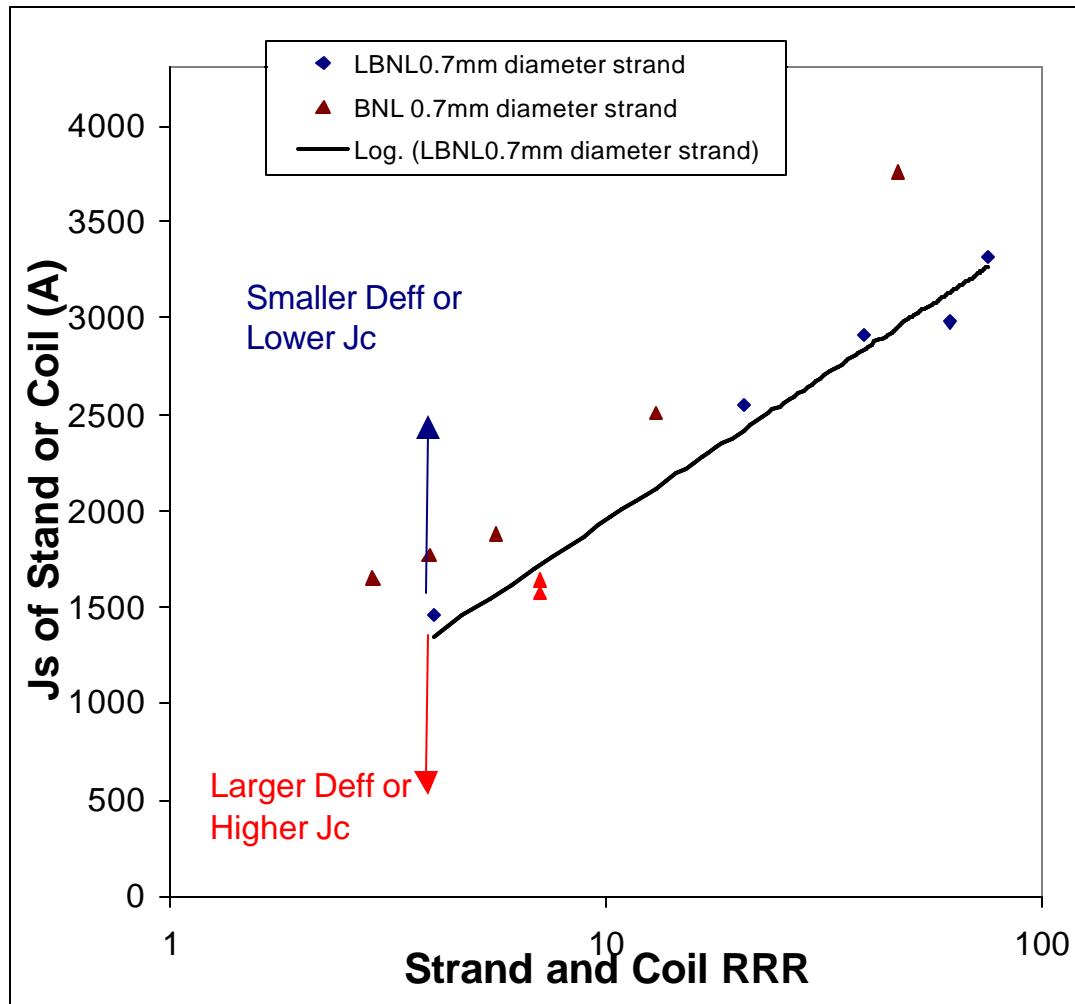
Heat-Treat Optimization





LBNL - Stability of Strands

D. Dietderich (NAPA, Oct'04)

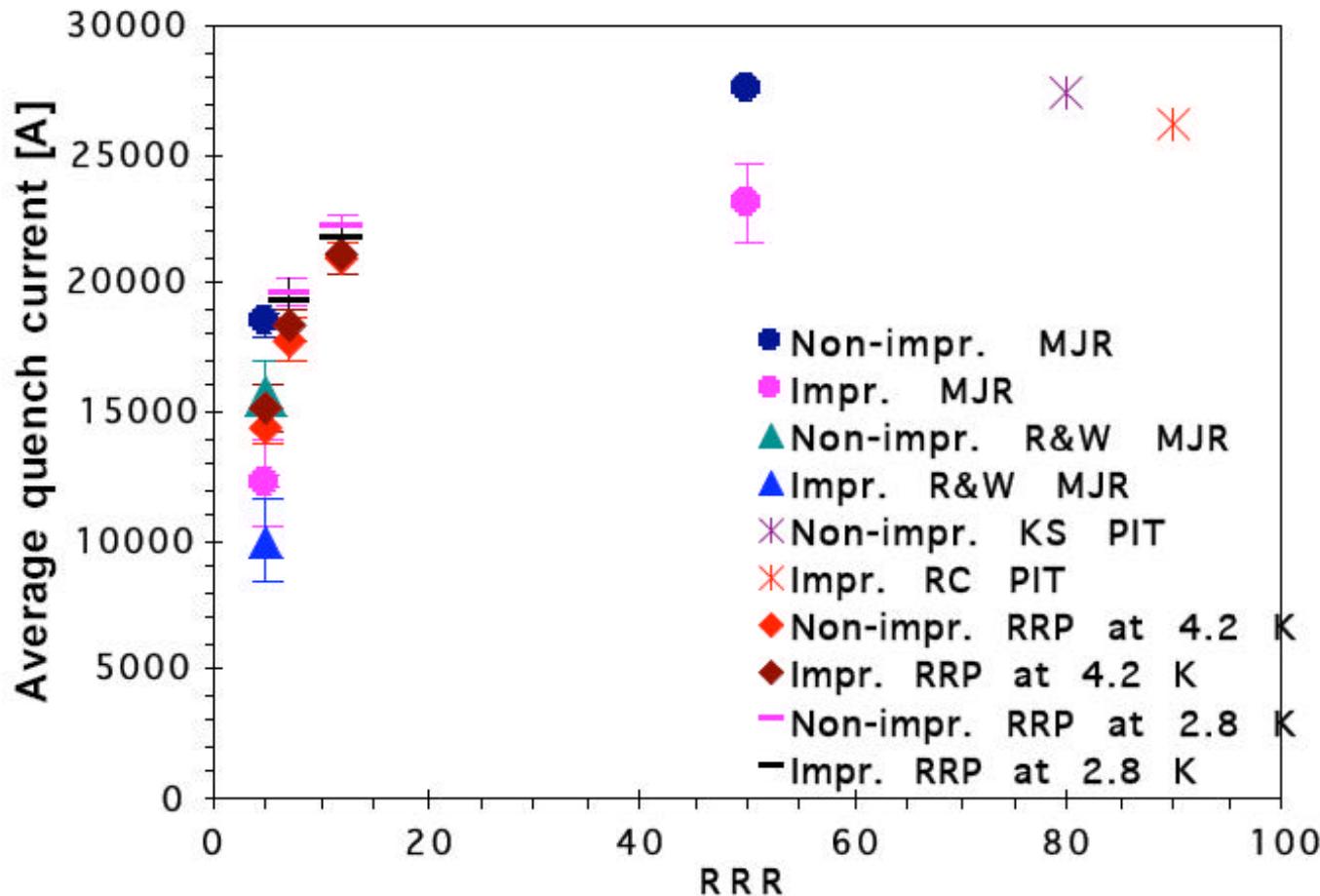




FNAL-Stability Meas. of Cables

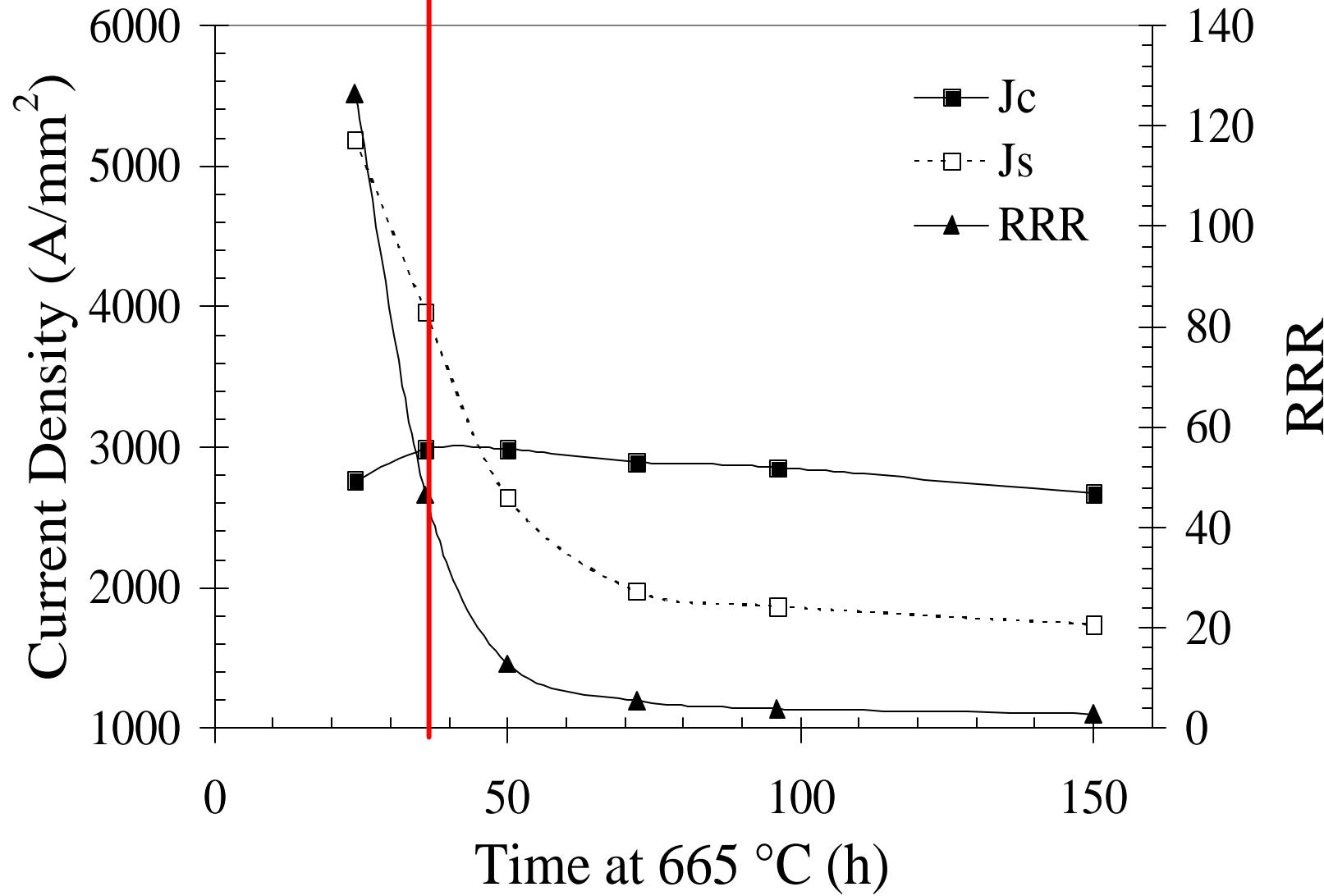
E.Barzi (NAPA Oct'04)

USING 28 kA SUPERCONDUCTING TRANSFORMER





BNL - 0.7mm RRP (54/61)





Cable R&D

Main Objectives and Features

- This sub-program will handle the immediate needs of Rutherford cable fabrication for the TQ and SQ magnet development. In particular, cabling parameters for these cables will be optimized to reduce the distortion of the strand internal structure and hence the degradation of the strand at the minor edge of the cable. This task will be closely tied to Strand R&D and the needs of the magnet that are being built under the LARP program.
 - Determine the final cable parameters for the first quad magnets TQ1a and TQ2a.
- The overall mission of cable R&D is to determine the cable parameter space (keystone angle, width, and thickness) for different strands (internal tin, powder-in-tube, plus wire with different internal geometries).
 - Develop methods to fabricate wide cables with a large keystone angle.



Cabling Procedure

- Present Nb₃Sn cabling procedure at LBNL
- Fabricate cable
 - Slightly over size
 - Anneal at 200C/2-4 hrs
 - Softens Cu and cable contracts by ~0.25% in length
 - May harden Sn core
 - Re-roll to decrease thickness by 25-50 mm.
 - Compacts cable making it mechanically stable



Cable Parameters for LARP Quadrupole Magnets

Parameter s	Units	Prototype I	Prototype II	TQ Prototype	Tolerance
Strands in cable	No.	20	39	26, 27 or 28	NA
Strand diameter	mm	0.7	0.7	0.7	+/- 0.002
Width	mm	7.8	14.34	10.077 max.	+0.000, -0.100
Thickness	mm	1.27	1.20	1.26	+/- 0.010
Keystone angle	deg.	0.89	0.95	1.0	+/- 0.10

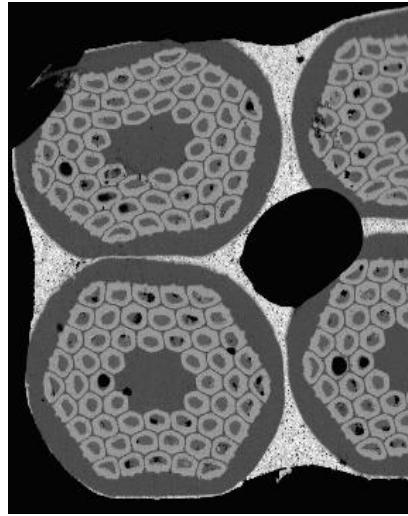
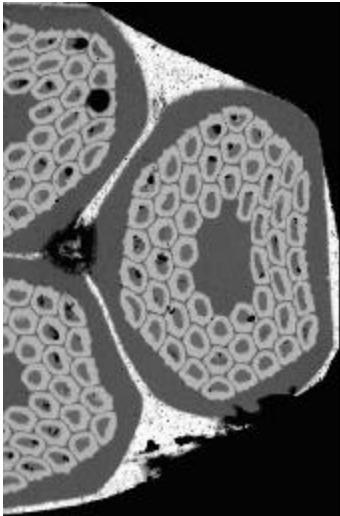
Mechanically
stable, no
damage at edge

Mechanically
unstable, 20% Ic
Degradation



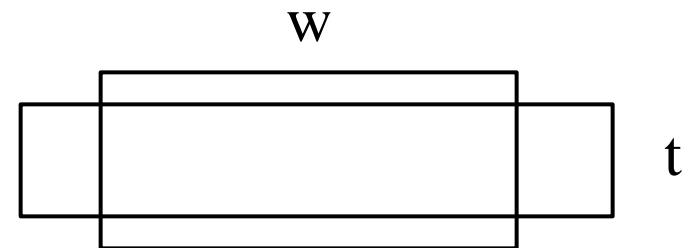
Cable Compaction-D. Dietderich

Decouple thickness & width



0.8 mm strand diameter
40 Strands
 $\text{Area} = 20.11 \text{ mm}^2$
87.57% Compaction

Problem with Area Compaction



2 Cables: Same compaction

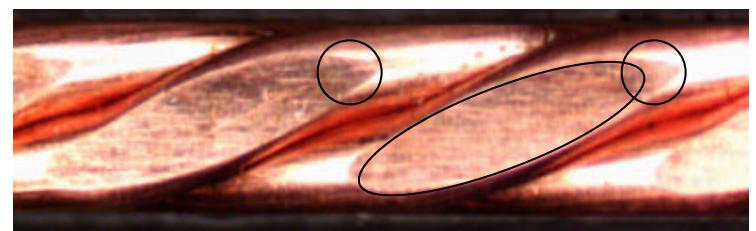
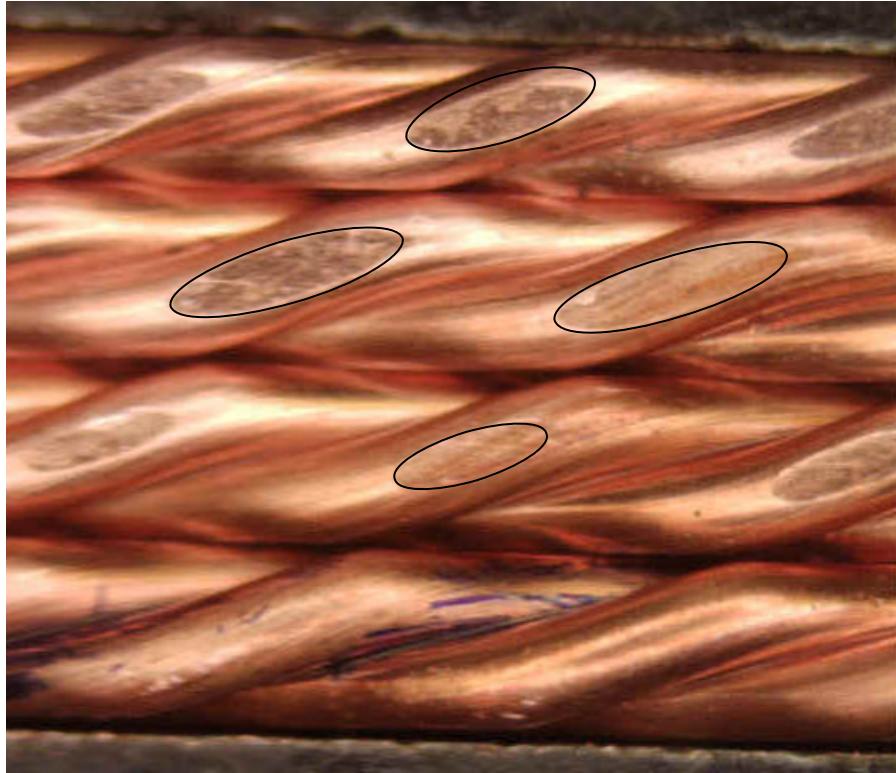
$$\begin{array}{l} 14.4 \text{ mm} \times 1.400 \text{ mm} = 20.16 \text{ mm}^2 \\ 14.0 \text{ mm} \times 1.440 \text{ mm} = 20.16 \text{ mm}^2 \end{array}$$

0.4mm half a
strand diameter



Quantify Cable Deformation (D.Dietderich)

- Area of edge facet



- Large facets: deformation too high
- Potential for real time monitoring



TQ prototype cable

- Explore effect of cable parameters, in particular the number of strands and keystone angle on mechanical stability, strand deformation and Ic degradation.
- Using MJR 54/61 design strand from FNAL



TQ-Magnet Expt. Cable Parameters

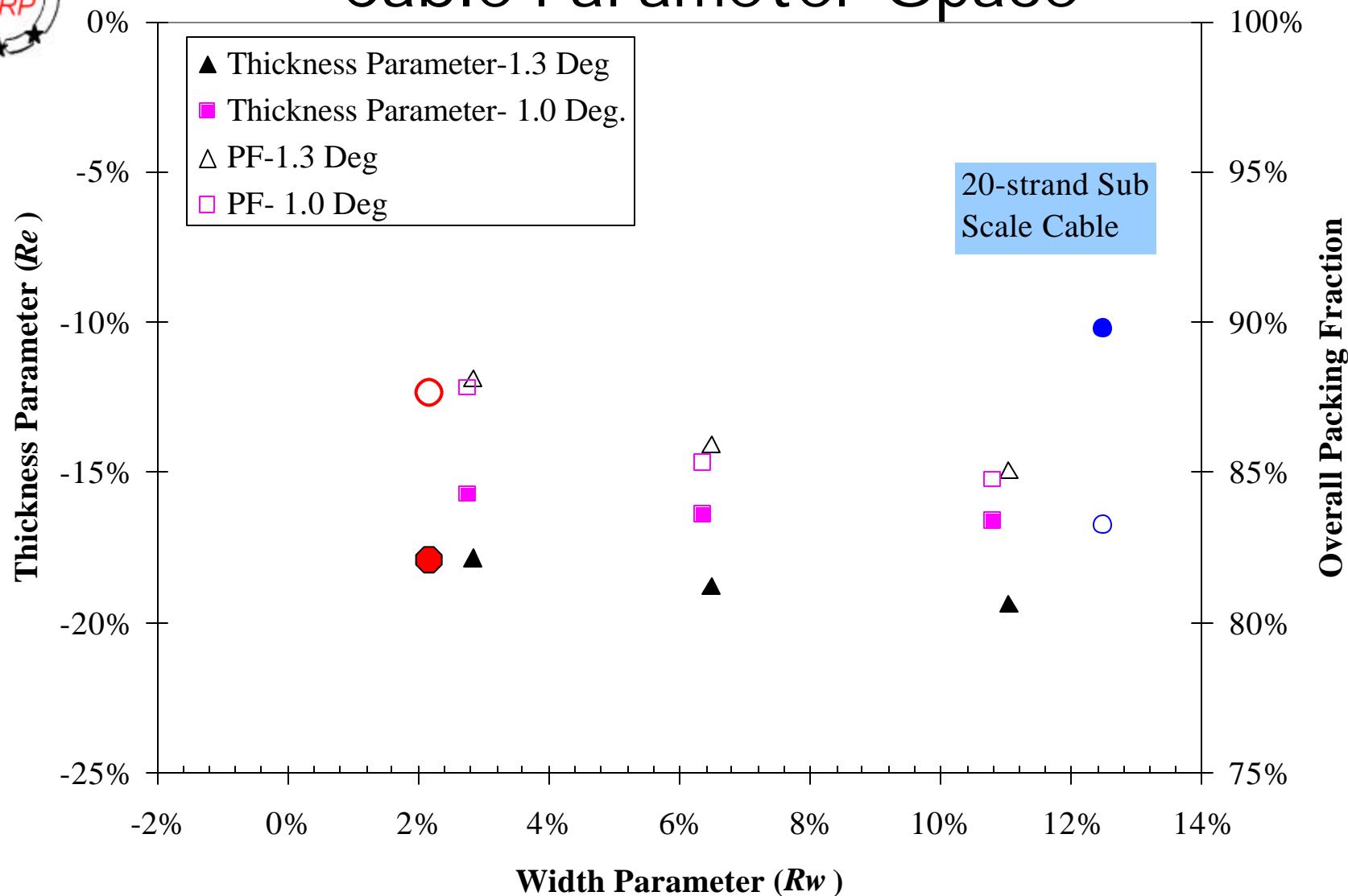
Sample ID #	910-A	910-B	910-E
No. of Strands	28	27	26
Avg. THICKNESS mm :	1.323	1.313	1.308
Avg. WIDTH mm :	10.088	10.043	10.02
Avg. ANGLE deg.:	0.996	0.964	1.377
Pitch Length mm :	80	80	62
FINISHED LENGTH m	4.2	4.2	4.2
Residual Twist deg/m	120	180	-

Sample ID #	913R-A	913R-B	913R-C
No. of Strands	28	27	26
Avg. THICKNESS:	1.274	1.267	1.264
Avg. WIDTH:	10.033	10.012	9.981
Avg. ANGLE:	1.019	1.047	1.058
Pitch length mm	80	80	62
First Pass Rect / Keys	K	K	K

Sample ID #	910R-A	910R-B	910R-E
No. of Strands	28	27	26
Avg. THICKNESS mm :	1.2689	1.2567	1.2552
Avg. WIDTH mm :	10.039	10.024	10.011
Avg. ANGLE deg.:	1.297	1.312	1.357
Pitch Length mm :			
FINISHED LENGTH m	4	4	4
Residual Twist deg/m	0	0	0



Cable Parameter Space





Ic of Strands Extracted from LARP Proto-type Cables

	Strand 205	Cable with 1.3° KS					
	Virgin	910R-E	910R-E	910R-B	910R-B	910R-A	910R-A
# strands		26	26	27	27	28	28
BNL							
11T	533	541	537	512	-	526	544
12T	442	450	446	421	421	443	453
RRR	11.5	12.7		12.3			10.3
FNAL							
12T	413			374			
15T	197	170		180		173	
OST							
12T	410-430						

BNL/FNAL
OST

210C/48h+400C/48h+**665C/72h**
210C/100h+340C/48h+**650C/180h**



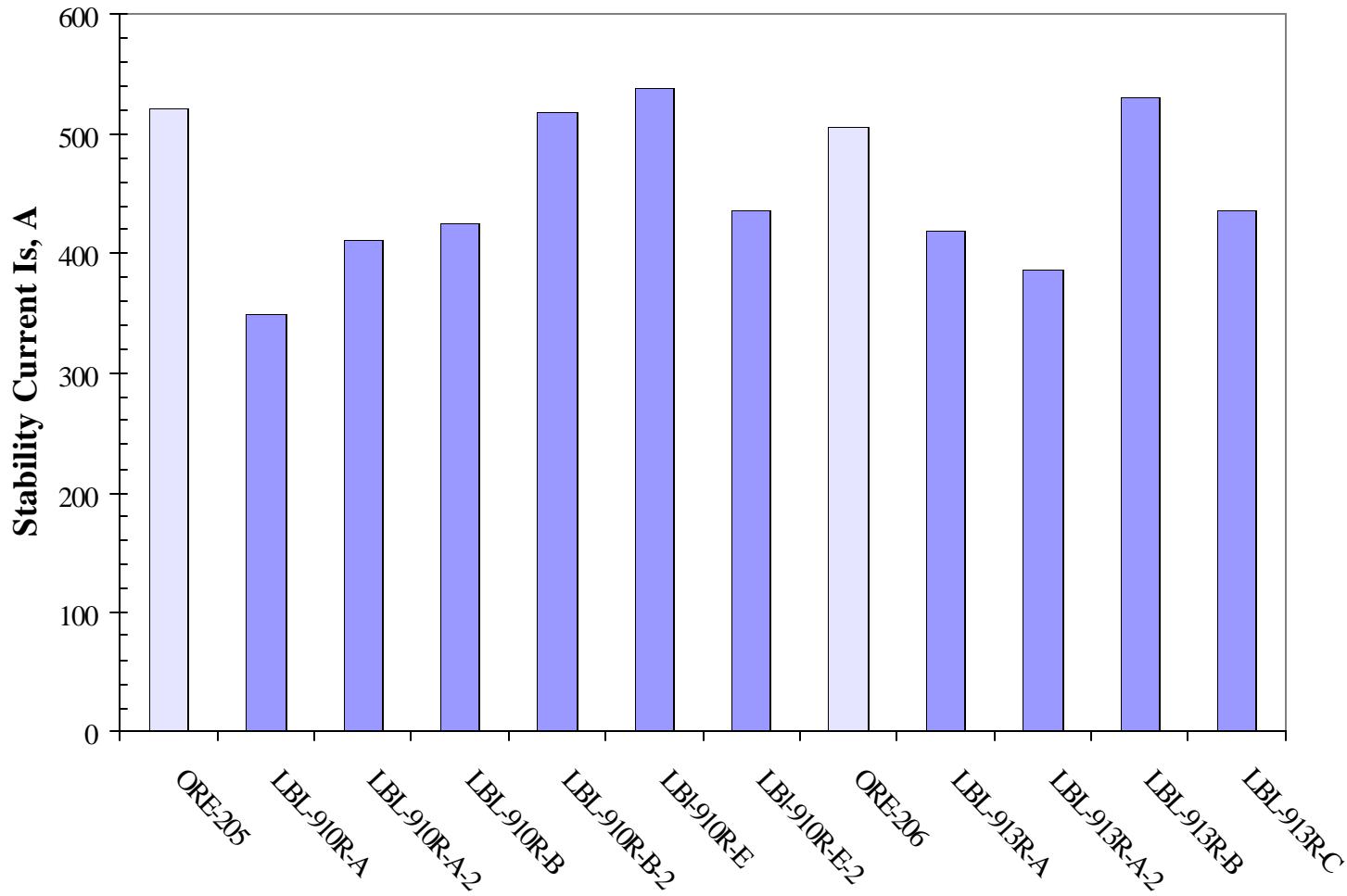
Ic of Strands Extracted from LARP Proto-type Cables

	Strand 206-C	Cable with 1.0° KS					
	Virgin	913R-C	913R-C	913R-B	913R-B	913R-A	913R-A
# strands		26	26	27	27	28	28
LBNL							
11T	528	518		522		518	
12T	432	424		428		428	
RRR	6.4	6.3		NA		9.5	
BNL							
11T	529	518		513		523	522
12T	442	430		424		426	425
RRR	11.6	13.3		10.8			13.1
OST							
12T	414-416						

BNL		210C/48h+400C/48h+ 665C/72h	
LBNL		210C/48h+400C/48h+ 680C/72h	
OST		210C/100h+340C/48h+ 650C/180h	



Stability Threshold Current





Microscopy

- Metallographic examination of the strands of the *1.0 deg.* cable made at LBNL show that the 28-strand cable shows *localized barrier breaks* in the inner rows of sub-elements which lead to Sn-contamination in the inner copper core, but shows no evidence of completely sheared sub-elements which would lead to Ic degradation. Sub-elements have excess Sn for complete reaction of Nb3Sn.
- 27-strand cable does not suffer from this defect.



Schedule and Status

- TQ1 proto-type cable fabrication: 01/6/2005
- Finalize cable envelop for TQ1a & 2a: 12/06/2004
- Finalize number of strands in cable: 4/8/2005
- Practice-winding cable for TQ's 4/30/2005
 - HER strand
 - Prototype TQ1a cable with RRP
- Production TQ1a cable: 5/30/2005
- Production TQ2a cable 7/30/2005
- Production SQ02 cable:
- Fabricate TQ1b cable:



Cable Testing

- FNAL:

- 28 kA SC transformer with fast (200kHz, 8-channel) DAQ for tests at self-field (1.8 T)

- Small racetrack coils for tests at field

- BNL: Cable test facility, 7 T max, 25,000 A max

- LBNL: Sub-scale racetrack coils for tests at field

- Other Possibilities

- FRESCA facility at CERN

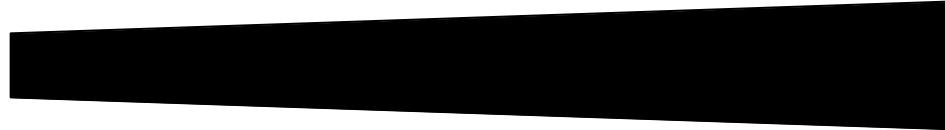
- 10T, 1.9K-4.2K, 30 kA

- NHFML

- Split-pair 12T magnet, Test cables under transverse load



End of Presentation



$$Re = t_1/D$$

$$Rw = 2D/(nd \cos\phi)$$



CDP/HEP- Inventory

Billet	Type	Stack	Diameter (mm)	Length (km)	Weight (kg)	received		Jc(12T)
7419	RRP	54/61	0.8	7471	34		\$	2890-3000
7424	RRP	54/61	0.8	8144	36.4		\$	2830-2960
7776	RRP	60/61	0.7	593	2		\$	2900
7904	RRP	126/127	0.7	3580	12.1	12/8/2005	R&D	2400
7904	RRP	126/127	0.6	3648	9.1		R&D	2000
7933	RRP	60/61	0.7	7580	25.7		\$	2350
7946	RRP	60/61	0.7	6691	22.7		\$	2150
7981	HER	37/37?	0.8	2179	9.7	12/8/2005	R&D	1950
7981	HER	37/37?	1.615	1131	20.5		R&D	
8079	RRP	90/91	0.7	6203	21	12/28/2005	R&D	2400
xxxx	RRP	54/61			30	4/5/2005	\$	
xxxx	RRP	54/61			70	9/15/2005	\$	